Tending

G Kerr, Forestry Commission Research Agency, Farnham, UK

Introduction

Tending generally aims to improve the composition, structure, condition, health, and growth of forests, in both single cohort and multicohort stands, to achieve management objectives. The scientific basis of a range of tending operations is described with reference to stands arising from artificial regeneration (planting (*see* **Afforestation**: Stand Establishment, Treatment and Promotion - European Experience) or direct seeding), natural regeneration (natural seeding (*see* **Silviculture**: Natural Stand Regeneration) or coppicing (*see* **Silviculture**: Coppice Silviculture Practiced in Temperate Regions)), or a mixture of both approaches. As with any silvicultural treatment, tending must be conducted with a clear understanding of the way in which the vegetation and site will develop after treatment. If the work is conducted with little foresight costs can be incurred with few, or possibly negative, effects on the development of the stand.

Tending Operations

The nomenclature of tending is an area of silviculture where terminology can be parochial and confusing. For example, the term 'singling' has many different meanings and 'formative pruning' can be translated into French in a number of different ways. For clarity, the terminology used here follows *The Dictionary of Forestry* (see Further Reading). The range of operations considered is illustrated in **Figure 1** and described below.

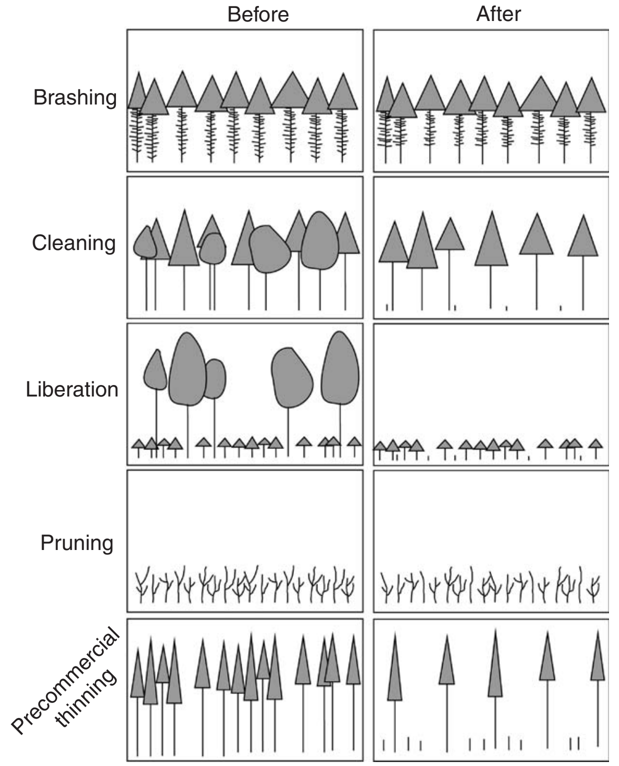

Figure 1 Diagrammatic representation of the effects of tending operations on forest stands.

Brashing

Brashing is the removal of live or dead branches on a tree stem from ground level up to a height of about 2.5 m. It is usually applied to planted single cohort stands at or just after the time of crown closure. The direct effects of brashing on a stand of trees are insignificant in terms of growth and timber quality. However, there can be indirect effects: increased access aids early identification of damage or health problems, and facilitates subsequent intermediate treatments.

Cleaning

Cleaning is a release treatment made to free selected trees from less desirable individuals that overtop them or are likely to do so (**Figure 2**). Cleaning has significant direct effects on the growth rate of selected trees because it increases access to resources. The main limiting resource is often assumed to be light in single cohort stands because cleaning has obvious effects on the canopy. However, on many sites greater access to light, water, and nutrients will all be important even though on some sites a single factor can be limiting, for example on dry sites greater access to moisture may be most critical. The main indirect effect of cleaning is the removal of 'undesirable' species and this may reduce the biodiversity of the stand. This is an important consideration if social or environmental management objectives are a priority, and in such woodlands there is no need for the undesirable species to be eliminated.

Liberation

Liberation is a release treatment to free a young cohort from competition with much larger sized trees. In many circumstances a liberation cutting corrects a problem not addressed by earlier silviculture. For example, the larger trees may be of species

Figure 2 Cleaning would now be desirable in this stand of northern hardwoods where pin cherry (*Prunus pennsylvanica*) is now dominant.

and sizes that could not be utilized from a previous felling and were left to reduce harvesting costs. The influence of these trees on the cohort of younger trees will depend on their number, basal area, and distribution. The presence of such trees is not always negative and they can increase species richness, improve vertical structure, and provide shelter for the younger trees; they could be girdled to increase standing deadwood.

Pruning

Pruning is the removal, close to the branch collar, of side branches and multiple leaders from a standing tree (*see* **Plantation Silviculture**: High Pruning). It is widely practiced to simulate natural branch mortality and increase the timber quality of selected trees. A secondary function of pruning is to act as a semipermanent way of marking tree selections to guide future thinning decisions. In general it is only used on 'young' trees where some degree of genetic improvement has been possible (**Figure 3**), otherwise it is really a remedial treatment for stands where production of quality timber is an important objective but establishment has not provided enough trees to achieve this.

Figure 3 Pruning *Pinus radiata* to produce knot-free timber.

Precommercial Thinning

Precommercial thinning is the removal of trees not for immediate financial return but to reduce stocking and concentrate growth on the more desirable trees. The effects are similar to cleaning except that, because the trees are generally older, they are dominating the site to a greater extent and the risk of losing control of the vegetation, to coppice regrowth or regeneration of pioneers, is much less. In addition, although precommercial thinning can remove less desirable species, with consequent effects on stand diversity, it is usually associated with removal of poorer phenotypes of the more desirable species.

Weeding

Weeding is a release treatment that eliminates or suppresses undesirable vegetation. The most likely need is in the period between establishment and first thinning to remove climbers such as *Clematis* spp., *Lonicera* spp., and kudzu (*Pueraria lobata*).

General Points

When tending operations are being considered the trees are established and safe from the normal adverse influences common to the site. However, trees will still need to be protected from a range of biotic and abiotic factors. A special case of this is the grey squirrel (*Sciurus carolinensis*) in the UK and Ireland. Grey squirrels can cause significant damage to a range of broadleaved species and trees are most vulnerable to damage when they are 10–40 years old (**Figure 4**). It is interesting to note that this behavior of the grey squirrel is very different to that in its native North America.

The future changes in appearance, species composition, productivity, and structure of a stand are largely governed by the spatial arrangement and height distribution of trees in the phase of growth between establishment and first thinning. Tending operations are an initial opportunity to influence this development. However, the costs of the operations can be high and, relative to decisions concerning establishment and thinnings, the long-term effects of some tending operations are uncertain. Hence, when forestry practice is subject to economic scrutiny tending operations are vulnerable. For example, in traditional French silviculture regenerating oak (*Quercus robur* and *Q. petraea*) has traditionally used a series of weeding and cleaning operations, but recently there has been much pressure for rationalization and the number of operations carried out has been significantly reduced. Similarly when regenerating northern hardwoods on the Allegheny plateau in northwest Pennsylvania, USA, almost no tending operations are carried out (**Figure 5**).

Stand Development

There are several classification schemes to describe stand development. A convenient one to set tending operations in context is shown in **Figure 6**. The model describes how the stand structure of a forest changes following disturbance (*see* **Silviculture**: Forest Dynamics).

After harvest or disturbance young trees regenerate on the site and this is classified as the stand initiation phase. As the young trees grow they form a dense canopy which eliminates further regeneration and

Figure 4 Grey squirrel (*Sciurus carolinensis*) damage to *Fagus sylvatica* in the UK.

Figure 5 Naturally regenerated northern hardwoods (mainly *Prunus serotina*); little tending will take place before the first thinning.

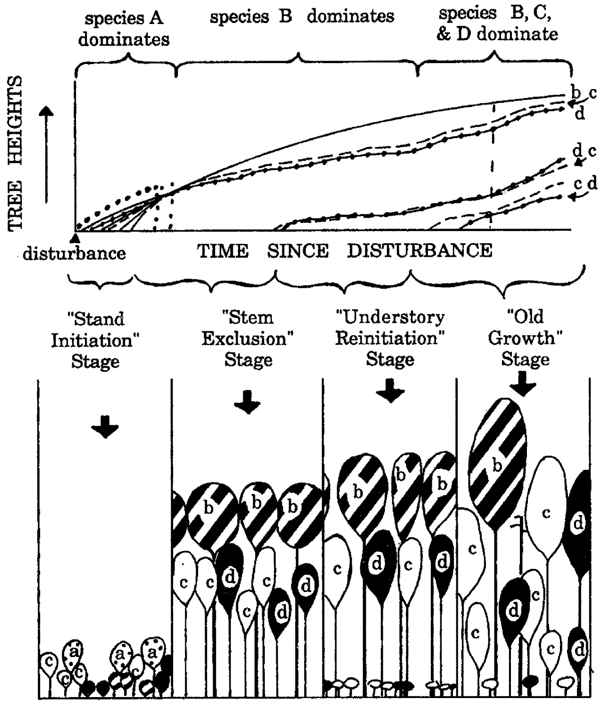

Figure 6 Schematic stages of stand development after disturbance. All trees forming the forest regenerate soon after the disturbance; however, the dominant tree type changes as stem number decreases and vertical stratification of species progresses. The height attained and the time lapsed during each stage vary with species, disturbance, and site. Reprinted from Oliver CD and Larson BC, *Forest Stand Dynamics*, update edn, Copyright © 1996 John Wiley & Sons, Inc. Reprinted by permission of John Wiley & Sons Inc.

existing stems start to die; the stand is in the stem exclusion stage. When openings form in the canopy as a result of a reduction in canopy competition, conditions for regeneration of the understory improve during the understory reinitiation phase. Eventually large trees in the main canopy die, younger trees in the lower canopy are released, and the stand develops into the old growth phase that has an all-aged structure with an irregular canopy. In single cohort stands, tending operations take place in the latter stages of the stand initiation phase and the beginning of the stem exclusion stage. Stocking is one of the primary factors that influences the development of stands moving from the stand initiation phase to the stem exclusion phase (*see* **Plantation Silviculture**: Stand Density and Stocking in Plantations). Hence the changes described below will occur sooner in an area with dense stocking, from successful direct sowing or natural seeding, compared with a planted area where costs usually prohibit stocking levels that will induce mortality quickly.

During the stand initiation phase tree crowns will not be in contact and, although the trees will be in competition for light, water, and nutrients, they can physically expand their crowns. At the point of crown closure, or soon after, the leaf area index reaches a maximum and the trees totally dominate the area. After crown closure, which is the start of the stem exclusion phase, trees begin to alter their shapes in response to the competitive environment. Foliage in the lower crown dies; as a result branch mortality commences and the growth rate of each tree decreases and the stem shape becomes less tapered. During this period of intense competition between trees (i.e., involving intimate physical crown contact) the stand is in the plastic phase as stem shape changes (**Figure** 7). During this phase the future crown classes of individual trees as dominants, codominants, intermediates, emergents, or suppressed is governed by a complex interaction of factors.

As the stand continues to develop the foliage area of the crowns remains constant but it moves further from the forest floor. At a point where the trees are fully utilizing site resources, or a where there is a constraining factor (e.g., water on a dry site), volume growth will slow dramatically, trees will become unstable due to high height : diameter ratios, height growth will stop, and possibly ‘stagnation’ will result. Stagnated stands contain trees that are very stressed and which therefore can be much more vulnerable to a range of biotic and abiotic damaging agents.

As mentioned above, the time taken for a single species, single cohort stand to stagnate is influenced mainly by stocking. This is illustrated in **Figure** 8a; stand A is initially dense but is cleaned at age x and has a precommercial thinning at age y to ensure that it does not enter the zone of stagnation. Stand B has a much lower density of trees at the end of establishment phase and this means that it will not stagnate in the period when tending operations are being considered. **Figure** 8a is a theoretical consideration and the zone of stagnation is narrow and well defined. However, in reality other factors in addition to stocking determine when, or even if, a stand stagnates; these include the inherent variability of the site, variation in age of regenerated trees, and genetics. This is illustrated in **Figure** 8b where the zone of stagnation is wider and entry into it is later compared with theory. If the stand is also multispecies a further significant factor is added that will delay the onset of stagnation, particularly if the tolerances of shade of the various species are different. In summary, and reality, although theoretically many stands with no intervention will develop towards a stagnant state there are many factors that slow this process.

In multicohort stands there are, by definition, two or more sizes of trees present and at some point in the development of the stand one of the cohorts will be

Figure 7 Dense oak stand (*Quercus robur* and *Q. petraea*) in the plastic phase of growth.

in the phase where tending operations may be required (**Figure 9**). Most growth per tree and usually per hectare occurs in the tallest cohort and manipulation of this will have the most direct effect on yield (*see* **Silviculture**: Unevenaged Silviculture). The taller cohort will also have a high degree of control over site resources: light, water, and nutrients. The lower cohort(s) can therefore reach a stage where a resource limits growth quite quickly. This is illustrated in **Figure 8**c where the zone of stagnation is less well defined and much wider, and trees can enter into it at much younger ages compared with single cohort stands. Hence, a primary concern in the management of multicohort stands is to ensure that younger trees do not lose vigor because of the ability of taller trees to dominate competition for site resources.

One area where understanding of stand development is lacking is in the ability of trees to recover from stagnation caused by periods of competition well beyond the normal intervention cycle (tending or thinning). For example, a common observation is that European ash (*Fraxinus excelsior*) will stagnate relatively quickly and generally does not recover. In contrast, European silver fir (*Abies alba*) takes much longer to stagnate and, after release many years later, can quickly resume a height growth trajectory determined by the site rather than its past competitive position. This is illustrated in **Figure 10**: at age *x* species A responds quickly to release but species B is slower. Later, at age *y*, both species respond to intervention less well although the decline in species B is much more marked than with species A. At present, understanding of these growth patterns is confined to general descriptions at the species level without much knowledge of the mechanisms involved.

Application of Operations to Guide Stand Development

The main guiding principles in the application of tending operations are:

1. To avoid conditions where the stand may stagnate.
2. To steer the stand towards the structure and composition that will achieve management objectives.
3. To achieve cost effectiveness.

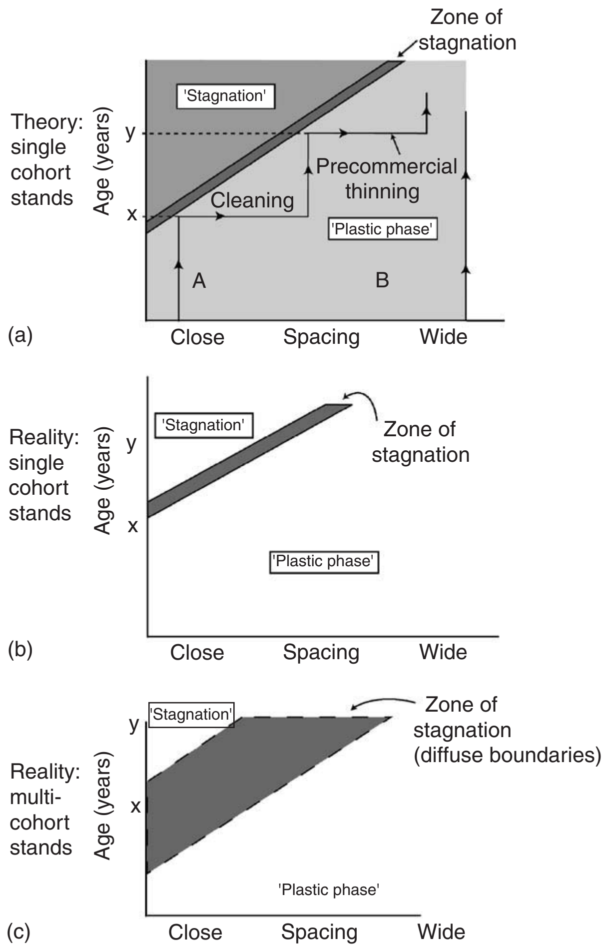

Figure 8 Relationship between tending regimes, stand development, and the zone of stagnation.

Different tending operations can influence stand development to a lesser or greater extent. Brashing and pruning can achieve specific objectives but, as discussed earlier, their influence on stand development is limited. However, cleaning, liberation, and precommercial thinning can have a significant effect on stand development.

The following points should be considered with respect to guiding stand development using tending operations:

1. How did the stand develop into its present condition?
2. What would be an appropriate operation now?
3. How will the stand develop after tending?

How Did the Stand Develop into its Present Condition?

No tending operation should be undertaken without some understanding of how the stand developed into the situation where intervention was required. For example, if drastic early cleaning is required this may reflect ecological conditions suboptimal for the selected trees or some other failure of establishment. In these situations the most important question to answer is: can the situation be remedied at acceptable cost? If not, the forest manager may have to adjust plans to take account of these changed circumstances rather than spending large sums of money fighting the natural processes that are operating on the site.

Specifying an Appropriate Operation

The structure and stage of development of the forest stand generally dictates whether the operation should be a cleaning, liberation, or precommercial thinning. However, the timing of the operation is less clear-cut and often the decision involves consideration of a number of factors such as labor and logistics, in addition to biological criteria. An example where an understanding of stand development is important for deciding the timing of a tending operation is with cleaning, where the species being removed can coppice. If the operation is carried out too early and the coppice is not killed using herbicides, there is a danger that the coppice shoots will grow into the canopy and have deleterious effects on the selected trees. In these situations it is invaluable to have some knowledge concerning the implications of delaying operations, if only to ensure that the products removed from the stand could be marketed in some way to offset the cost of the operations.

Another example of where knowledge of the effects of varying the timing of an operation is important is in cleaning hardwoods out of conifer natural regeneration. An interesting case study of this has been documented on a young stand of longleaf pine (*Pinus palustris*). In the trial the treatments were to remove the hardwoods when the pine was aged 1, 2, 3, 4, or 8 years and a control (untreated); the density of the pine was equalized in all treatments at age 4. By age 30, pine density ranged from 1482 to 1976 ha^{-1} in released plots and there were few differences in terms of diameter, height, and volume due to the different timings of the operation. However, there were significant differences with the untreated plots; competition had reduced the number of pines to 632 ha^{-1}, and the trees were smaller, with 8–10 times less utilizable volume. In conclusion, release was necessary, but delaying it at least for a few years did not diminish long-term volume production.

In most cases where a liberation cutting is required the trees to be cut will have little timber value,

Figure 9 Tending of groups of young trees in multicohort stands can be important if they are very dense.

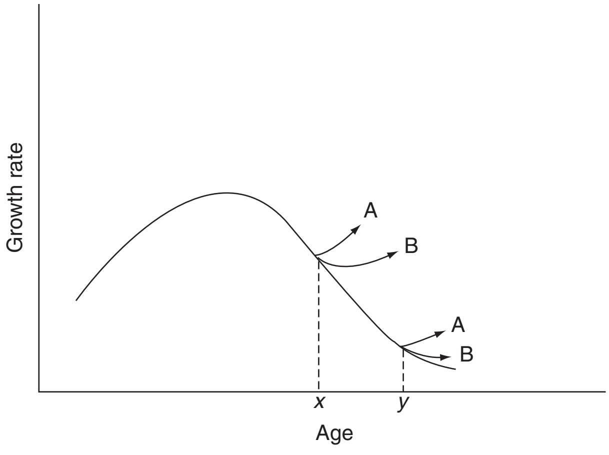

Figure 10 Changes in the responsiveness of two species to tending at different ages.

especially if they have been left with a lot of growing space so that they develop wide, spreading crowns and have all the characteristics of a 'wolf tree'. The main factor influencing when they can be removed is the physical impact of felling and extraction on the younger ones. The effects on the younger trees and the cost of the operation can be minimized by killing the trees with safe and judicious use of herbicides. This can have a positive affect of creating (or increasing) a resource of standing deadwood but this must be balanced against any possible risk to people using the forest, especially if they have been invited or encouraged into the forest for recreation. If the liberation is by cutting this will have most benefit and damage the younger trees least if it is done when the younger trees are small (less than knee high) and when the weather is not cold and frosty, to reduce the possibility of young trees snapping.

The question of how to remove the competitive effect of trees is perhaps more straightforward compared with the timing of the operation. The competitive effects of trees can be removed by cutting or killing using herbicides, or a mixture of both. If trees are to be cut a major consideration is the limitations of the equipment available; this can also influence when the operation is carried out. Herbicides can be used to kill trees by spraying foliage or by applying the herbicide to a cut in the stem. There are many factors to consider with the safe and judicious use of herbicides. A combination of cutting and herbicides can also be used, for example, to prevent coppice regrowth after cleaning.

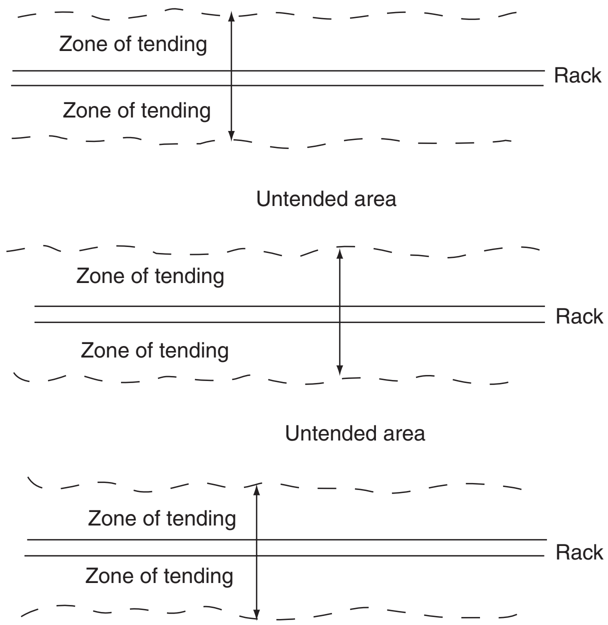

Figure 11 Rack cutting in young naturally regenerated stands to reduce costs.

If a decision has been taken that in order to fulfil management objectives a stand must be cleaned or have a precommercial thinning this will usually apply to the whole stand. However, if as with most tending operations, this is done at a cost to the landowner, treating a proportion of the stand is one way of reducing costs. Two examples of how this can be done are rack cutting and selective release.

Rack cutting This is commonly used in Denmark, France, and Germany. Parallel racks, 1 m wide, are cut every 12–16 m (*n*) through natural regeneration at an early age. Cleaning and respacing is then carried out 3–4 m (1/4*n*) on both sides of the rack, so that roughly only 50% of the crop is treated (**Figures 11** and **12**). The racks improve access and so reduce the cost of respacing, while dividing the stand for management purposes.

Selective release One method of achieving this is the cleaning and releasing of two stems (about 2 m apart), at intervals of approximately 7–8 m through the stand so that they can develop to pole size. Each favored tree is cleared to a distance of 1.2–1.5 m radius and the intervening matrix is untouched.

Prediction of How the Stand will Develop After Tending

The most likely source of information on how any one stand will react to the tending operation is by accumulated experience of treating similar stands on equivalent sites. There are a few models that can be used by the forest manager to help decision making; perhaps the best-known are those for *Pinus radiata* grown as plantations in New Zealand (**Figure 3**).

Figure 12 Cleaning oak (*Quercus robur*) in France showing racks (see also **Figure 11**).

Conclusion

Tending is the application of intermediate treatments after establishment but before the first thinning. The main guiding principles in the application of these operations are: (1) to avoid conditions where the stand may stagnate; (2) to steer the stand towards the structure and composition that will achieve management objectives; and (3) to achieve cost effectiveness. Factors influencing decisions concerning tending in single cohort and multicohort stands are different because in the latter large trees significantly influence the availability of light, water and nutrients to younger trees.

Tending operations can significantly improve stand productivity; but as they are labor intensive they may not always be cost effective and are therefore under pressure in forest management systems.

See also: **Afforestation**: Stand Establishment, Treatment and Promotion - European Experience. **Plantation Silviculture**: High Pruning; Stand Density and Stocking in Plantations. **Silviculture**: Coppice Silviculture Practiced in Temperate Regions; Forest Dynamics; Natural Stand Regeneration; Unevenaged Silviculture

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Thinning

P Savill, University of Oxford, Oxford, UK
J Evans, Imperial College London, Ascot, UK

Introduction

Thinning is an operation that artificially reduces the number of trees growing in a stand with the aim of hastening the development of the remainder. It is normally carried out several times and starts a few years after the canopy closes. The trees removed are usually the same species as the trees favored. In many situations in forestry about 3000 trees ha^{-1} may be planted, or when natural regeneration is relied upon, the number may be 250 000 or more. The mature stand contains no more than 300 trees ha^{-1}, and with some broadleaved species fewer than 100. Thus, a minimum of around 90% of all trees established at the start of a rotation are removed before the end in thinnings.

Competition can be manipulated by foresters either by the spacings used at establishment (in planted forests), or by thinning after the trees have grown for some years, or both. Thinning is carried out for a number of reasons:

1. To reduce stand density and hence to reduce competition, leaving the remaining trees more space for crown and root development. This promotes stem diameter growth and usable sizes are reached more quickly.
2. To remove dead, dying, and diseased trees, or any others that may cause damage to the remaining healthy ones.
3. To remove trees of poor form: crooked, forked, or coarse trees, so that future growth is concentrated only on the best trees.
4. To provide the owner with some revenue though, if this is not possible, as in some early thinnings, in the expectation of greater returns later in the rotation.
5. More occasional reasons include maintaining light beneath the canopy to encourage grass growth for grazing, for providing poles for building, or for amenity, recreational, or ecological reasons.

Responses of Crops to Thinning

Thinning a stand reduces the number of trees competing for light, soil moisture, and nutrients. This has a number of effects on the remaining trees:

1. Natural mortality (or self-thinning) is reduced because the remaining trees have better access to the resources needed for growth.
2. The lower branches of the crowns receive more light, and so remain alive for longer, hence the trees have deeper crowns than in unthinned stands.
3. The increased space round a tree after thinning promotes the growth of shoots, foliage, and roots. The crown expands outwards to occupy the gap left in the canopy where the neighboring tree was felled. The resulting greater photosynthetic area increases growth.
4. Diameter growth increases significantly. Height growth is little affected.
5. Because thinning mainly affects diameter growth, the stems in thinned stands taper more rapidly than in otherwise similar unthinned stands.